THE HELIOMICROMETER

By GEORGE E. HALE

The measurement and discussion of photographs of the sun made with the spectroheliograph involve a large number of processes, some of which have been satisfactorily worked out, while others are still under consideration. Up to the present time special attention has been devoted to the following points:

1. The measurement of the heliographic positions of flocculi, with reference to the determination of the solar rotation.

2. The measurement (with the monocular micrometer of the Zeiss stereocomparator) of the relative distances from the center of the sun of corresponding points in the calcium (Hα) and hydrogen (Hβ) flocculi, with reference to the relative level of these objects.

3. Comparative studies, with the same instrument, of the forms of flocculi, as photographed with various lines.

4. Photometric determinations of the relative brightness, at various distances from the sun's center, of the flocculi and the adjoining photosphere, as bearing on the level of the flocculi and the absorption of the solar atmosphere.

5. Photometric measurements similar to (3), but especially adapted for the determination of the level of sun-spots.

6. Stereoscopic studies of the flocculi.

7. Studies of the flocculi with a kinetoscope, with reference to their changes in form.

8. The measurement, by a photometric method, of the areas of flocculi in regions ten degrees square, for the study of variations in the solar activity.

Spectrographic studies have also been made; particularly of the hydrogen and calcium lines, for the purpose of interpreting the spectroheliographic results.

The present paper deals with the measurement of heliographic positions; the other methods of measurement and reduction will be described later.

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The determination of the heliographic positions of sun-spots, as carried on at Greenwich, involves the measurement of their polar co-ordinates, and a simple calculation, facilitated by the use of tables. As the average number of spots on each photograph is small, only a moderate amount of computing is required, and the method has apparently proved satisfactory after many years of service. For the flocculi the case is different. The average number of flocculi suitable for measurement on a single plate may reach forty or fifty, thus involving a large amount of computing in the aggregate. Furthermore, the lack of sharpness of the flocculi (as compared with spots), and their rapid changes of form, rarely permit of the precision of setting attainable in the case of spots, and render a different mode of measurement feasible. It will appear, however, that in its perfected form the instrument described in this paper is capable of giving results no less precise than the ordinary measuring machine.

The first and simplest form of the instrument, which I devised for the measurement of the Kenwood spectroheliograph plates by Mr. Fox at the Yerkes Observatory, consists of a metallic globe, with smooth white surface, upon which the solar image is optically projected. The axis of the globe being set at the inclination required by the date of the photograph, and the plate properly oriented, it is only necessary to read off the heliographic latitudes of the flocculi and their differences in longitude from the sun’s center, by the aid of parallels and meridians ruled, one degree apart, on the surface of the globe. The results obtained with this simple device were so satisfactory that it is still regularly employed in the measurement of the Rumford spectroheliograph plates. The essential condition to be met is that the angular diameter of the globe, as seen from the projecting lens, shall equal the angular diameter of the sun, as seen from the earth.¹

In the second form of the instrument, as constructed in the shops of the Solar Observatory, two 4-inch (10 cm) telescopes were mounted parallel to one another. One of these pointed at a globe, 60 feet (18.29 m) distant, beside which stood the solar photograph to be

¹ A full description of this instrument will soon appear in a paper by Mr. Fox and myself on the solar rotation.
PLATE XVIII

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measured, with its center in the optical axis of the other telescope. The images of globe and plate, as formed by the two telescopes, were brought together in a single eyepiece, by means of a half-silvered prism. After the photograph had been oriented and centered on the globe, by adjustments controlled from the observer's seat, the latitudes and longitudes of the flocculi were read off with respect to parallels and meridians, ruled one degree apart, on the surface of the globe. This instrument gave good results, but the illuminated surface of the globe (black lines on a matt silvered surface) interfered with the visibility of the minute flocculi. Experiments with cross-hairs for setting purposes, and the desire to secure a higher degree of precision than estimates to a tenth of a degree could afford, soon led me, by successive steps, to the design embodied in the "helio-micrometer," which is illustrated in Plate XVIII.

The two 4-inch telescopes, of 60 inches focal length, which were used in the second form of the instrument described above, are retained and mounted immediately above the globe and the plate-carrier. These telescopes point to the centers of two optically plane mirrors, mounted on a concrete pier at a distance of about 30 feet (9.14 m). In the telescope on the right, the solar image, brilliantly illuminated by transmitted light, is seen after reflection from one of the plane mirrors. In the same way the globe, illuminated by reflected light, may be seen in the telescope on the left. The images are brought together in a single eyepiece, with the aid of a right-angle prism at the end of each telescope and a half-silvered prism, similar to that used in the monocular eyepiece of Zeiss's stereocomparator, mounted a short distance in front of the eyepiece.

As a complete description of the apparatus will be published later, only its general features are described in the present paper. The adjustments of the plate-carrier permit the photograph to be raised or lowered, moved right or left, rotated for orientation, and moved toward or from the mirror. Cross-hairs, mounted immediately in front of the plate,¹ are controlled from the eyepiece, and their intersection can be made to coincide with the flocculus to be measured. While settings are thus being made, the object-glass of the telescope which points to the globe is covered by a swinging shutter, controlled

¹ The same support carries the electric pen, referred to below.
by the observer. Under these conditions the details of the solar photograph are seen with great clearness, and settings are made as easily and rapidly as in any form of measuring machine.

The entire globe has a matt silvered surface, and one hemisphere shows no lines except the equator and central meridian. These lines do not quite reach the center of the globe. At the point where they would intersect, a small circular black dot is engraved. This is brought into coincidence with the intersection of the cross-hairs, by rotating the globe in longitude and latitude. In longitude the globe has both quick and slow motions, permitting a rapid and accurate setting to be made. In latitude a single motion, consisting of a worm-gear operated by an arm with double Hooke's joint, gives sufficiently rapid motion, combined with perfect control. The longitude circle, provided with a vernier reading to tenths of a degree, or, if desired, to 2′, is read with a telescope from the eye-end. The globe is then turned back to zero longitude, and at this point the latitude circle, also reading to tenths of a degree or to 2′, is read with a second telescope.

The vertical axis that carries the fork in the opposite bearings of which the horizontal axis of the globe rests, can be set at any desired angle, read by means of a vernier and divided circle. The inclination of this axis corresponds to the tabulated latitude of the center of the sun for the date of the photograph.

It is unnecessary to give here the details of the adjustments of the apparatus. It may be added, however, that the photographs made with the Snow telescope and 5-foot spectropheliograph are oriented by the aid of control plates, on which the solar image is allowed to drift between two exposures. A line joining two images of the same flocculus gives the east and west direction. The angle between this line and a line drawn on the plate by the image of a needle-point mounted in contact with the collimator slit provides the means of orientation. The centering of the solar image on the globe is easily effected, with the aid of a metallic screen mounted in front of the globe and bearing a black circle, adjusted so as to be exactly concentric with the globe. This circle should coincide, when the instrument is in adjustment, with a black circle etched in a glass plate permanently fixed in the adjustable plate-carrier. This circle is
slightly larger in diameter than the solar photograph which can thus be centered with great precision. In order to provide for the varying size of the image, due to the varying distance of the sun from the earth, the plate-carrier can be moved along rails, so as to change its distance from the telescope with which it is observed. The necessary adjustment of focus is made by moving the object-glass of the corresponding telescope.

Measurements are confined to objects within fifty degrees of the sun's center. This is for the purpose of avoiding errors inevitable when spots or flocculi are measured in the near neighborhood of the sun's limb. Furthermore, it is not necessary, within this limited region, to change the focus of the telescope used to observe the globe.

In testing the heliomicrometer, a photograph of the sun was measured with this instrument and with an ordinary measuring machine, giving polar co-ordinates. After the reductions had been completed, it was found that the latitudes and longitudes of the flocculi, measured in the two ways, agreed within the limits of error of settings (one or two tenths of a degree). The operations of measurement proved as rapid with the heliomicrometer as with the other measuring machine, and all the time required for calculations was saved. A further test was made by measuring the positions of certain sun-spots, which also appear on the Greenwich photographs. Mr. Maunder was kind enough to give me the positions of these spots as determined at Greenwich. The results correspond within a few tenths of a degree, or as closely as could be expected under the circumstances.¹

It should be stated here that Dr. Frank Schlesinger, with whom I had the benefit of discussing the first globe measuring instrument used at the Yerkes Observatory, suggested, in 1902, that an ordinary theodolite, provided with a small pointer in place of the telescope, might give good results in this work. The details of the apparatus were not worked out, and I had forgotten the suggestion, when I was led by the above described steps to the adoption of the same principle, namely, the use of divided circles in place of meridians and parallels ruled on a globe. This important element in the design

¹ The centers of spots on spectroheliograph plates are often slightly displaced by overhanging flocculi.
is therefore due to Dr. Schlesinger. It is evident that a globe is not really required (as a pointer might suffice), but it has the advantage of permitting one surface to be divided into ten-degree squares, used as described below.

My attention has been called, by Professor A. E. Douglass, to his paper published in *Popular Astronomy* (No. 42, 1897), entitled "The Astronomer's Globe." This globe was used for the solution of spherical triangles. The positions of markings on Mars were also plotted on the surface of the globe, and their latitudes and longitudes read off with the aid of two divided semi-circles, which could be moved over the surface. The same, of course, could be done with sun-spots. I do not understand that any system of optical projection was used with this globe.

It will be readily seen that the heliomicrometer can be used as a stereocomparator (with monocular or binocular vision). For this purpose it is only necessary to mount in front of the globe a second photograph, illuminated by transmitted light. Miss Ware, who is in charge of the heliomicrometer, uses this arrangement for comparing the forms of the flocculi photographed on successive days, in order to select points suitable for measurement. By means of an electric pen, controlled from the eyepiece, a small dot is made on the glass side of the plate, for purposes of identification, near each point selected.

One hemisphere of the globe is ruled with meridians and parallels ten degrees apart. When seen in projection on the globe (the axis of which is given the proper inclination for the date in question), the intersections of the squares can be marked on the glass side of the plate by means of the electric pen. Plates marked in this way are used by Miss Smith in her photometric measures of the areas of the calcium flocculi within ten-degree regions. The data thus secured are employed in our studies on the variation of the solar activity, with reference to the condition of the sun as a whole, and its activity in different zones of latitude and longitude.

The heliomicrometer could be improved by supporting all parts of the apparatus shown in Plate XVIII on a stone or concrete pier. The present instrument, which is fastened to a concrete floor and braced to an adjoining brick wall, gives very satisfactory results, but is less stable than if it had been designed anew, instead of being
modified from the second form of the instrument, described above. I am indebted to Mr. Pease for working out the detailed drawings.

In view of the rapidity of measurement, and the accuracy of the results obtained with this instrument, I can recommend it for the determination of the heliographic positions of spots and flocculi shown on direct photographs or on spectroheliograph plates.

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